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Remote Sensing of Environment 94 (2005) 155–171

Remote Sensing of Environment

www.elsevier.com/locate/rse

Using angular and spectral shape similarity constraints to improve MISR aerosol and surface retrievals over land

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Received 9 June 2004; received in revised form 13 September 2004; accepted 15 September 2004

Abstract

The Multi-angle Imaging SpectroRadiometer (MISR) instrument on the Terra satellite has demonstrated the capability to retrieve aerosol optical depths, surface bidirectional reflectance factors, and hemispherical reflectances over a wide variety of land surface types. In particular, its multiangular imaging design has enabled the application of algorithms that minimize sensitivity of the aerosol retrievals to the brightness of the underlying surface. The novel aerosol algorithm that was developed prior to launch has had notable quantitative success. Over certain scene types, however, the approach contained obvious spatial artifacts, so a postlaunch refinement to the algorithm was implemented. It constrains the retrieved aerosol models and optical depths such that the implied angular shape of the surface hemispherical–directional reflectance factor (HDRF) is similar among all of the MISR wavelengths. This upgrade has resulted in three tangible benefits: (1) the occurrence of outliers has been dramatically reduced, (2) correlations with AERosol RObotic NETwork (AERONET) aerosol sunphotometer data are quantitatively improved, and (3) the quality of surface products is markedly enhanced. MISR Level 2 aerosol and surface products are archived at the NASA Langley Atmospheric Sciences Data Center. Those having version numbers v0012 and higher incorporate this upgrade in the data processing software.

Keywords: MISR aerosol and surface retrieval; Multi-angle Imaging SpectroRadiometer (MISR); AERONET aerosol sunphotometer data

1. Introduction

Mapping of global and regional aerosol amounts and properties over land is of great interest for climate and environmental studies. In particular, the ability to deal with the broad variety of underlying surface conditions is essential to achieving global coverage. Satellite remote sensing of aerosols requires inferring particle properties from observed top-of-atmosphere (TOA) radiances. One of the principal challenges is separating the atmospheric signal (which contains information about aerosols) from surface-leaving radiances. This is often handled by making some assumption about the land surface absolute brightness. For example, in the case of the MODerate resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra and Aqua spacecraft, a systematic relation between the absolute surface reflectance in visible and short-wave infrared wavelengths is adopted (Chu et al., 2002; Kaufman et al., 2002). Near-ultraviolet mapping from the Total Ozone Mapping Spectrometer (TOMS; Torres et al., 2002) provides a unique approach in that most land surfaces are dark at these wavelengths. Other techniques take advantage of a difference in the characteristics of the surface-leaving and atmosphere-leaving radiance fields. For example, the

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0034-4257/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2004.09.009

Polarization and Directionality of Earth's Reflectances (POLDER; Deschamps et al., 1994) land aerosol algorithms assume spectrally independent surface polarization to retrieve an aerosol index comprised of the product of aerosol optical depth and Ångström exponent (Deuzé et al., 2001). Multiangle intensity imaging at kilometer and subkilometer resolution, e.g., from the Along-Track Scanning Radiometer successor instruments (ATSR-2 and AATSR; Stricker et al., 1995) and from the Multiangle Imaging SpectroRadiometer (MISR; Diner et al., 2002, 1998) take advantage of differing angular reflectance signatures of the surface and atmosphere to accomplish retrieval of aerosol optical depth over such surfaces (Martonchik et al., 2002, 1998; North et al., 1999; Robles González, 2003; Veefkind et al., 1998). Moderate spatial resolution multiangle imaging algorithms can also capitalize on the fact that land surface reflectance variations typically occur at higher spatial frequencies than scattered radiation from aerosol layers (Martonchik et al., 2002).

In this paper, we describe a major upgrade to the MISR aerosol retrieval algorithm over land. MISR is one of five science instruments aboard the polar-orbiting Terra spacecraft. It observes the Earth in reflected sunlight, and its typical data collection mode is to observe the Earth globally at nine different view zenith angles in four spectral bands (446, 558, 672, and 866 nm) with a cross-track ground spatial resolution of 275 m–1.1 km. The fore-aft cameras are paired in a symmetrical arrangement and acquire images with nominal view angles, relative to the Earth's surface, of 0°, 26.1°, 45.6°, 60.0°, and 70.5° for the cameras named An, Af/Aa, Bf/Ba, Cf/Ca, and Df/Da, respectively. The letters A–D denote the lens design (longer focal lengths are used at the more oblique angles to preserve spatial resolution) and "n", "f", and "a" indicated nadir, forward, and aftward viewing. The swath width of the An camera is 378 km, and the swath width of the off-nadir cameras is 413 km. Global coverage between $\pm 82°$ latitude is obtained every 9 days. After the 36 channels of imaging data are radiometrically calibrated, georectified, and averaged to a uniform resolution of 1.1 km, they are analyzed to determine aerosol properties over both land and ocean at a resolution of 17.6 km$\times$17.6 km. Using the derived aerosol information, land surface properties such as hemispherical–directional (HDRF) and bidirectional reflectance factors, hemispherical reflectances (albedos), leaf area index, and fractionally absorbed photosynthetically active radiation are derived at a 1.1-km resolution.

The algorithm improvement described in this paper was put into production in January 2003, and earlier data have been reprocessed. All MISR aerosol and surface products versioned v0012 and later include this improvement. MISR data products are available to the science community and the public through the NASA Langley Atmospheric Sciences Data Center (ASDC) at http://www.eosweb.larc.nasa.gov.

4. Conclusions

A simple model of surface directional reflectance that assumes spectral HDRFs can be separated into a function in wavelength multiplied by a function in angle provides powerful constraints on aerosol retrievals performed using multiangle data. This model is based on ATSR-2 heritage and is justified on physical grounds in that the scattering elements which make up most surfaces are large compared to the wavelength of visible and near-infrared light. Three lines of argument were then used to examine the validity of the constraints: (1) comparison of the angular and spectral shapes of surface HDRFs in AirMISR data for which the atmospheric characteristics were obtained entirely from independent sources, (2) comparison of the frequency of optical depth outliers in MISR aerosol products and prevalence of "quilting" in the resulting surface products, and (3) comparison of MISR aerosol optical depths against independent AERONET data, both with and without the algorithm upgrade. Each line of investigation supports the value of invoking the HDRF shape similarity criteria.

The examples presented in this paper suggest that over vegetated surfaces, for at least the view-illumination geometries we examined, and despite the large spectral reflectance difference between the visible and near-infrared, the angular reflectance shapes are similar, albeit not necessarily identical. Spectrally varying contrast between green vegetation and the underlying soil is expected to lead to angular shapes that have some spectral dependence. Nevertheless, for the scenes examined here, those differences appear to be subtler than the differences that can result from inaccurate atmospheric correction. Further refinements in our quantitative understanding of the spectral dependence of angular reflectance could lead to additional improvements in the aerosol retrievals and may have important ramifications for hyperspectral multiangular remote sensing of canopy structure. Investigation of the applicability of the surface angular shape constraint to homogeneous targets, without invoking the additional heterogeneity condition required by the MISR "HetSurf" algorithm, is the basis of an experimental algorithm ("HomogSurf") being explored by the MISR team. Application of such an approach to Case 2, turbid, coastal, and inland waters is one area where multiangular information could lead to innovative remote sensing advances.